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**Electrical Resistivity of Carbon-Carbon Composites**

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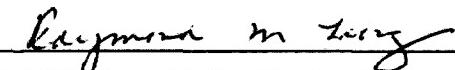
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## I. INTRODUCTION

X-ray diffraction (XRD) parameters have been shown to effectively monitor the progressive change in graphitic ordering with heat treatment in carbon-carbon composites. In addition, XRD parameters have been correlated with electrical resistivity and resistivity ratio. The resistivity ratio is the ratio of that property measured at the normal boiling point of LN<sub>2</sub> to the value at room temperature.<sup>1,2</sup> Electrical resistivity is especially useful for monitoring changes in graphitic ordering because it is relatively simple to measure.

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<sup>1</sup>G. S. Rellick and P. M. Adams, X-Ray Diffraction Studies of Carbon-Carbon Composites, TOR-0086(6645-01)-1, The Aerospace Corporation, El Segundo, Calif. (18 June 1986).

<sup>2</sup>A. D. Cull, Nondestructive Mechanical and Thermal Characterization of Five Involute, Low Risk, Carbon-Carbon Exit Cones, Southern Research Institute (April 1984).

## II. EXPERIMENTAL PROCEDURE

The objectives of this procedure were to (1) devise a simple, reproducible method for measuring the electrical resistivity and the resistivity ratio of carbon-carbon composite billets; and (2) verify the method by correlating measurements on "Peacekeeper" exit cone specimens with previously published data.

A four-point method of measuring sample resistance was selected to overcome problems associated with lead and contact resistance (see Fig. 1). Because sample geometry could vary substantially, flexibility was maintained regarding allowable geometry.

During the experiment, the principal problem was how to attach the current and voltage probes to the sample. Several techniques were investigated. The most successful technique was to insert the lead wire into a small hole drilled in the specimen. Good electrical contact was established by coating the end of the wire with electrically conducting paint. Nonconductive epoxy was then used on the wire/sample junction so the junction would be strong enough for the measurement process (Fig. 2).

A schematic diagram of the circuit used in the resistivity measurement is shown in Fig. 3. The circuit had a controlled current power supply, an ammeter, and a high impedance voltmeter. The current through the sample was adjusted to a convenient value between 250 and 500 mA. The voltage drop resulting from resistance of the sample was then determined. The measurement was performed with the sample at room temperature. The measurement was then repeated after the sample was immersed in LN<sub>2</sub>. The original room temperature measurement was reconfirmed after permitting the sample to return to room temperature.

To determine sample resistivity, the physical dimensions of the sample and the location of the voltage taps were used in conjunction with the measured sample resistance. The following relation was used

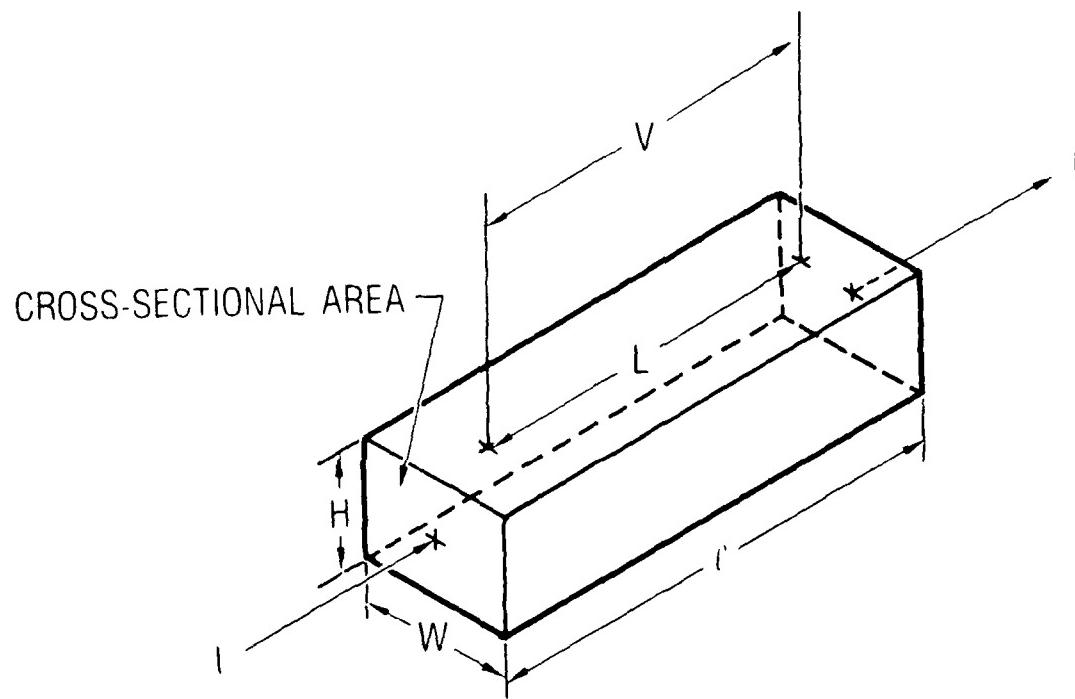


Fig. 1. Sample Geometry

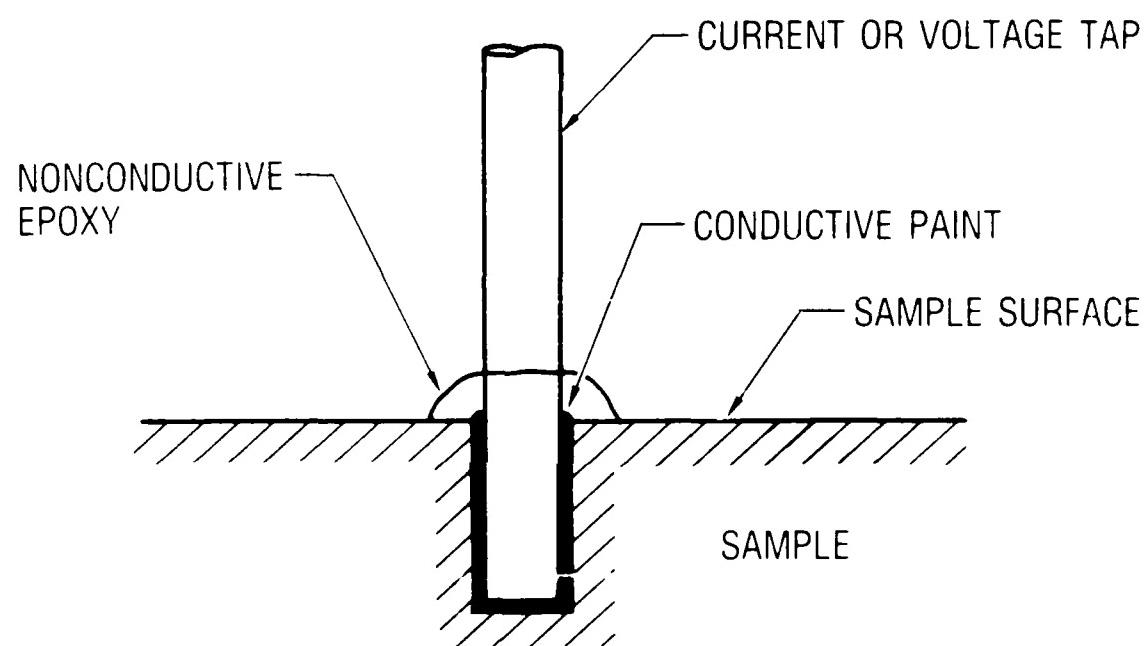


Fig. 2. Junction Construction

DC CURRENT SOURCE

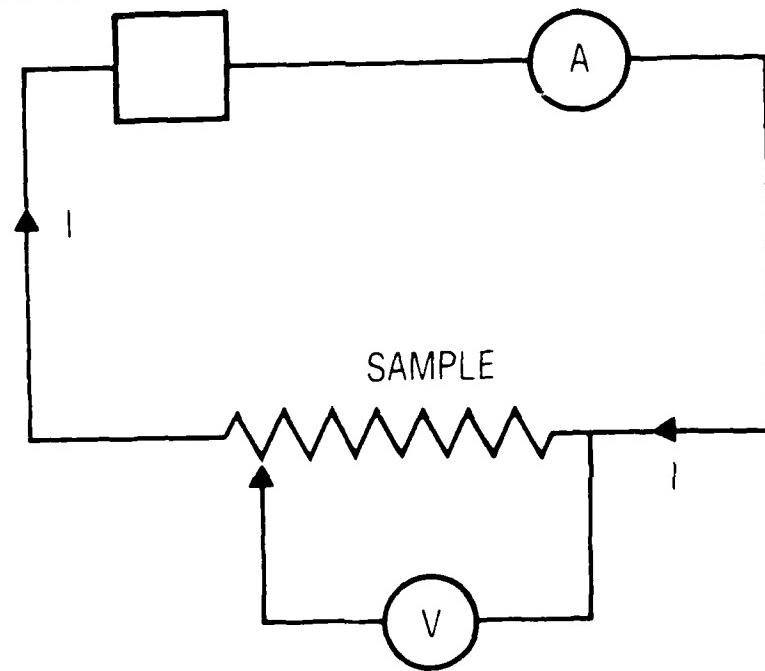


Fig. 3. Equivalent Measuring Circuit

$$\rho = A R/L \quad \text{ohm-cm}$$

where A is the cross-sectional area of the sample in the direction normal to the current flow in square centimeters, R is the resistance in ohms, and L is the distance between the voltage taps in centimeters.

The samples tested and the appropriate identifying and geometric parameters of the samples are listed in Table 1. The measured resistivity and resistivity ratio values are listed in Table 2.

Table 1. Samples

Sample No.	Sample ID	No. of Graphitic Cycles	Sample Height (cm)	Sample Width (cm)	Sample Length (cm)	Distance Between Voltage Taps (cm)
A	10042 SN 218-1	3	1.66	2.60	4.25	3.00
B	10042-013 SN 205	3	0.64	1.32	7.62	5.15
C	10042 SN 218-1	3	1.64	1.89	2.77	1.25
C1	10042 SN 218-1	3	0.85	1.62	1.86	1.20
D	10042 SN 218-1	3	0.35	0.90	---	4.50
F	10060 SN 125	1	0.30	0.60	---	5.00
G	10060 SN-3	2	0.30	0.35	---	5.20
H	10060 SN 126-1	1	0.40	1.00	---	4.70

Table 2. Resistivity of MX Exit Cone Samples

Sample No.	Date	Current Axis	$\rho$ 300 K ( $\mu\text{ohm}\cdot\text{cm}$ )	$\rho$ 77 K ( $\mu\text{ohm}\cdot\text{cm}$ )	$\rho$ 77/ $\rho$ 300
A(3G)	10/10/86	Warp	5000	6200	1.22
A	9/18/86	Warp	5300	6300	1.19
A	9/18/86	Warp	5000	(5400)	(1.08)
A	9/17/86	Warp	5100	6300	1.23
A	9/15/86	Warp	5100	---	---
B(3G)	9/18/86	Fill	5500	6100	1.11
B	9/15/86	Fill	5500	---	---
C(3G)	9/19/86	Cross Ply	9200	---	---
C1	10/17/86	Cross Ply	7000	7200	1.03
D(3G)	10/17/86	Warp	4800	5400	1.11
F(1G)	11/7/86	Warp	5200	7500	1.42
G(2G)	11/7/86	Warp	2800	3700	1.33
H(1u)	11/7/86	Warp	5800	7700	1.32

### III. CONCLUSIONS

The principal advantage of the method described is its simplicity: a reasonably precise estimate of the resistivity and the resistivity ratio can be obtained easily. However, one problem associated with the method is the possible loss of good electrical contact of one or more of the taps when immersing the sample at 77 K (normal boiling point of LN<sub>2</sub>). This loss of contact can be avoided if the taps are carefully and firmly attached. A conductive epoxy might be used instead of the conductive paint.

To obtain good results, it is important to accurately measure the dimensions of the sample and the distance between the voltage taps, L (see Fig. 1). It is also important that the cross section of the sample be uniform along the distance L. A simple error analysis indicates that an uncertainty of 5% in each of the measured parameters--length, height, width, and resistance--results in an estimated error of 20% in the resistivity.

In Fig. 4, the resistivity values are plotted as resistivity ratio versus room temperature resistivity. The figure includes previously published data for similar exit cone samples.<sup>1</sup> The previously published data fall into a family of curves that can be associated with the number of graphitization cycles undergone by the sample during processing. The data of the present work are consistent with these results, at least to within the estimated accuracy described.

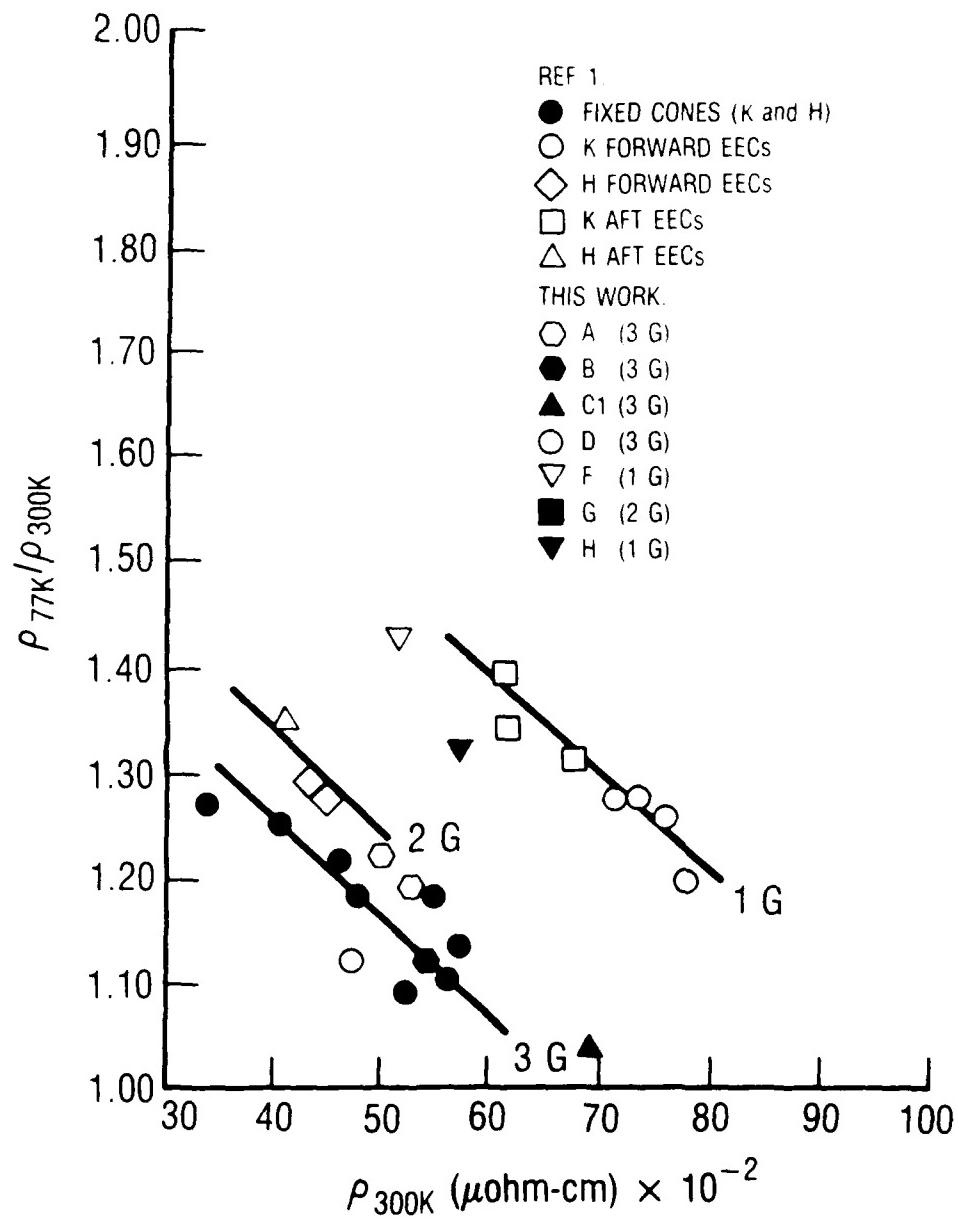


Fig. 4. Resistivity Ratio as a Function of Room Temperature Resistivity

## LABORATORY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security projects, specializing in advanced military space systems. Providing research support, the corporation's Laboratory Operations conducts experimental and theoretical investigations that focus on the application of scientific and technical advances to such systems. Vital to the success of these investigations is the technical staff's wide-ranging expertise and its ability to stay current with new developments. This expertise is enhanced by a research program aimed at dealing with the many problems associated with rapidly evolving space systems. Contributing their capabilities to the research effort are these individual laboratories:

Aerophysics Laboratory: Launch vehicle and reentry fluid mechanics, heat transfer and flight dynamics; chemical and electric propulsion, propellant chemistry, chemical dynamics, environmental chemistry, trace detection; spacecraft structural mechanics, contamination, thermal and structural control; high temperature thermomechanics, gas kinetics and radiation; cw and pulsed chemical and excimer laser development including chemical kinetics, spectroscopy, optical resonators, beam control, atmospheric propagation, laser effects and countermeasures.

Chemistry and Physics Laboratory: Atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiative signatures of missile plumes, sensor out-of-field-of-view rejection, applied laser spectroscopy, laser chemistry, laser optoelectronics, solar cell physics, battery electrochemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, thermionic emission, photo-sensitive materials and detectors, atomic frequency standards, and environmental chemistry.

Computer Science Laboratory: Program verification, program translation, performance-sensitive system design, distributed architectures for spaceborne computers, fault-tolerant computer systems, artificial intelligence, micro-electronics applications, communication protocols, and computer security.

Electronics Research Laboratory: Microelectronics, solid-state device physics, compound semiconductors, radiation hardening; electro-optics, quantum electronics, solid-state lasers, optical propagation and communications; microwave semiconductor devices, microwave/millimeter wave measurements, diagnostics and radiometry, microwave/millimeter wave thermionic devices; atomic time and frequency standards; antennas, rf systems, electromagnetic propagation phenomena, space communication systems.

Materials Sciences Laboratory: Development of new materials: metals, alloys, ceramics, polymers and their composites, and new forms of carbon; non-destructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures as well as in space and enemy-induced environments.

Space Sciences Laboratory: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation.